Far-Infrared Detector Technology Advancement Partnership

- "FIDTAP" -

Marty Mlynczak, Nurul Abedin, David Johnson, and Lelia Vann (NASA LaRC)

George Komar & Mariann Albjerg (NASA ESTO)

Henry Hogue, Maryn Stapelbroek, John Reekstin (DRS Technologies, Cypress, CA)





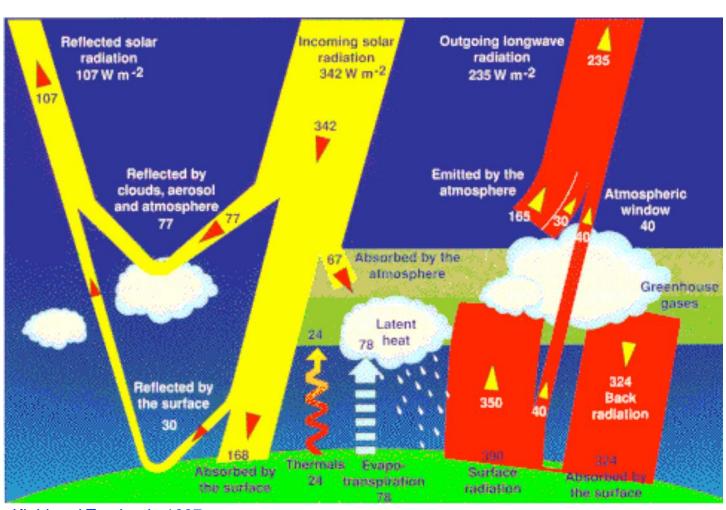


FITDAP

Outline

- Science Motivation and Justification for Far-IR Measurement
- FIRST Project Summary
- Development of far-IR instruments for Space
- FIDTAP
- Summary

Overview of Earth's Radiation Budget



Kiehl and Trenberth, 1997

FITDAP

A Brief History of Earth Radiation Budget Measurements

ERB measurements from space first proposed by V. Suomi in late 1950's

First quantitative measurement of Earth System from space was ERB in late 1950's, early 1960's

Measurement is of 2 "classic" energy flows:

- 1. Total Radiation = Emitted Thermal + Reflected Solar
- 2. Reflected Solar Radiation

Emitted thermal radiation obtained by subtraction of classic energy flows

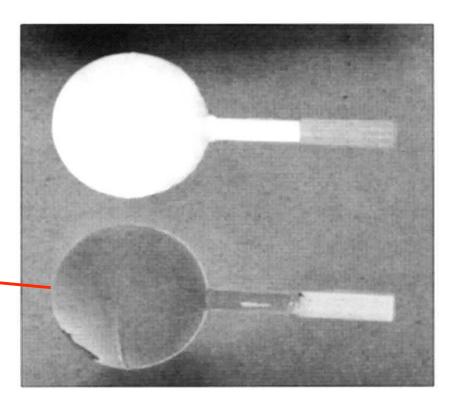
In the past 45 years these measurements have been refined in terms of:

- 1. Improved spatial resolution
- 2. Improved calibration
- 3. Improved angular sampling
- 4. Improved temporal sampling (GERB instrument on Meteosat)

One critical dimension remains – The Spectral Domain



Profs. Suomi and Parent with Explorer VII Satellite

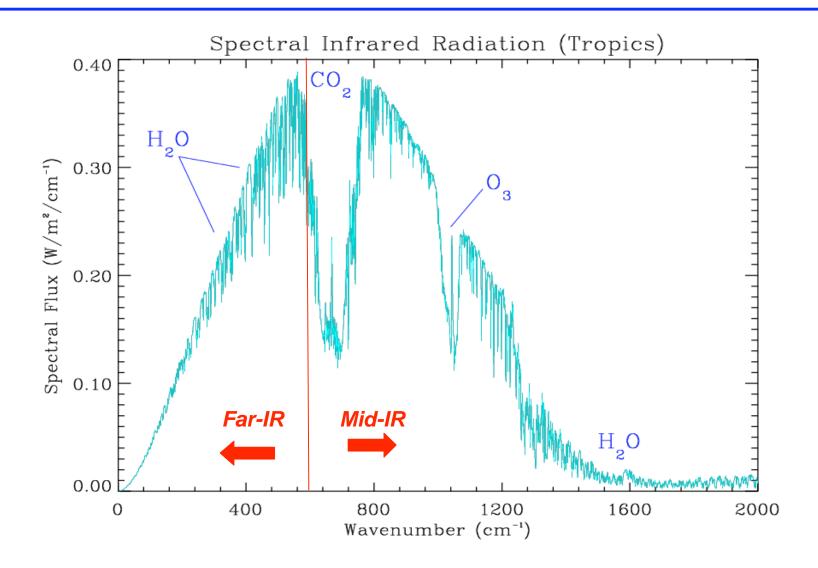


First Earth Radiation Sensors on Explorer VII

- Critical range of IR emission for Earth: 4 to 100 μm (2500 to 100 cm⁻¹)
- Earth Emission Sensors: ERB-type
 CERES, ERBE, GERB, SCARAB little to no spectral resolution
- Earth Emission Sensors: Spectral sensing type
 AIRS, MODIS, CrIS, IASI no sensing capability beyond 15.4 μm
- We define the Far-IR as the part of the spectrum longer than 15.4 μm
- This situation motivated us to propose FIRST
- FIRST developed by NASA Instrument Incubator Program (2001-2005)

FIRST = Far-Infrared Spectroscopy of the Troposphere

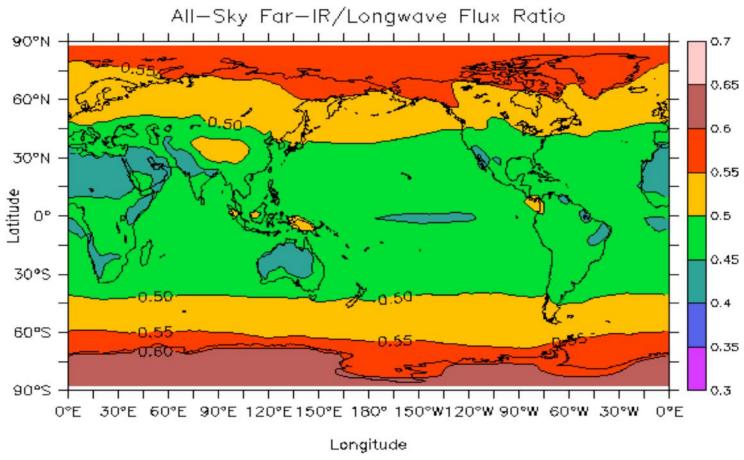




Compelling Science and Applications of the Far-Infrared

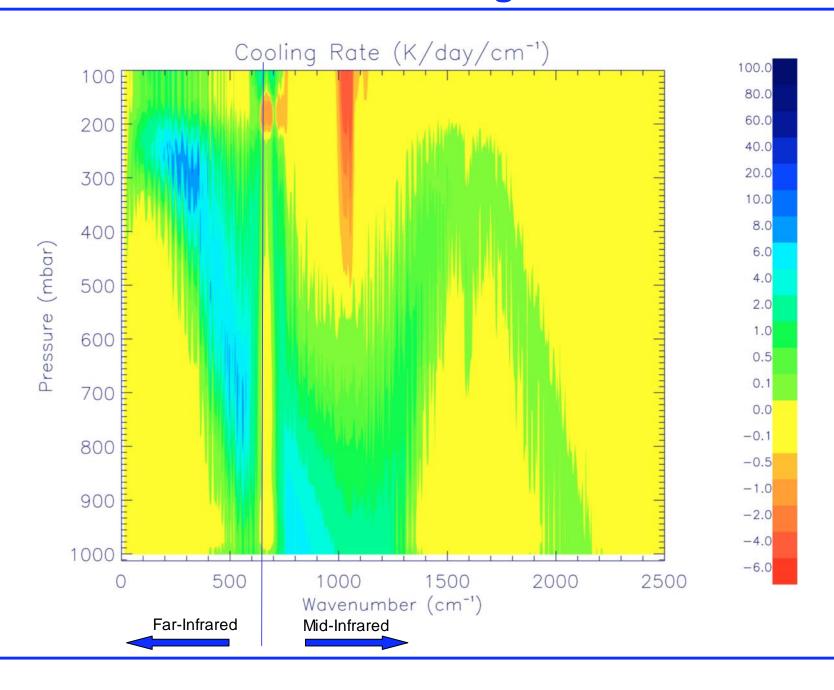
- Up to 50% of OLR (surface + atmosphere) is beyond 15.4 μm
- Between 50% and 75% of the atmosphere OLR is beyond 15.4 μm
- Basic greenhouse effect (~50%) occurs in the far-IR
- Clear sky cooling of the free troposphere occurs in the far-IR
 - Potential to derive atmospheric cooling rates directly from the radiances
- Upper Tropospheric H₂O radiative feedbacks occur in far-IR
- Cirrus radiative forcing has a major component in the far-IR
- Longwave cloud forcing in tropical deep convection occurs in the far-IR
- Improved water vapor sensing is possible by combining the far-IR and standard mid-IR emission measurements

Direct Observation of Key Atmospheric Thermodynamics



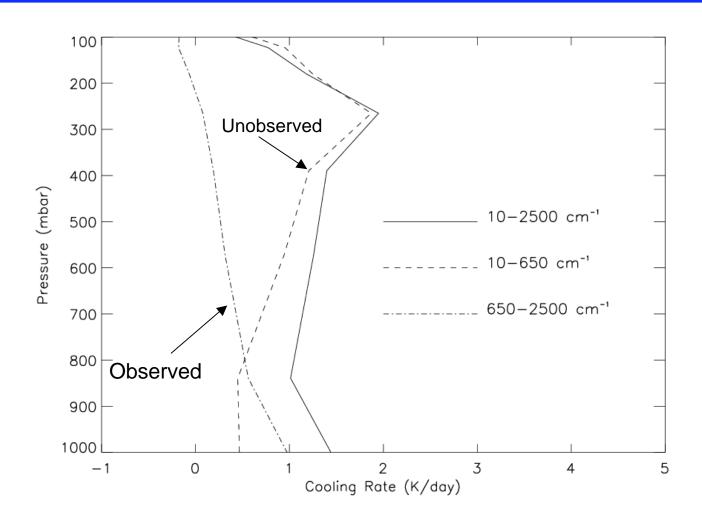
Annual mean TOA fluxes for all sky conditions from the NCAR CAM

Infrared Cooling Rate



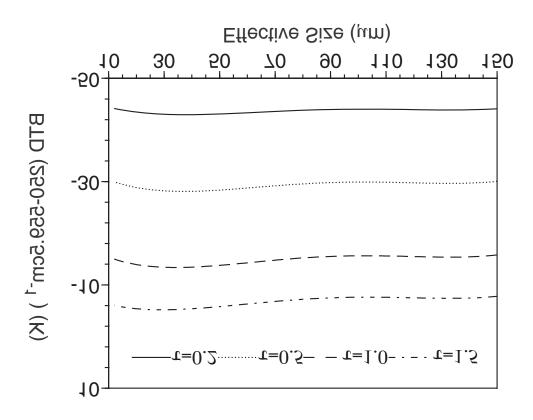


Far-Infrared Spectroscopy of the Troposphere



Spectrally Integrated Cooling – Mid-IR vs. Far-IR

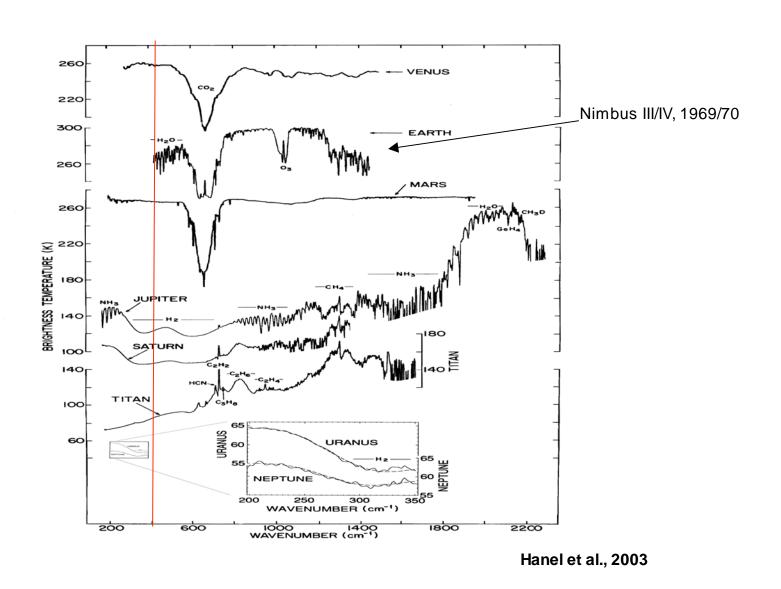
FIRST – Sensitivity to Cirrus Clouds



Brightness temperature difference between two channels v_1 =250.0 cm⁻¹ and v_2 =559.5 cm⁻¹ as a function of effective particle size for four cirrus optical thicknesses

FIRST spectra can be used to derive optical thickness of thin cirrus clouds (τ < 2). Reference: *Yang et al.*, JGR, 2003

Far-IR Measurements in our Solar System



Far – IR least measured from space on Earth!

FIRST System Performance Requirements

- At present, no extant sensor in development for spaceflight with spectral sensing capability longer than 15 μm wavelength
- FIRST developed technology needed to attain daily global coverage, from lowearth orbit, of the far-infrared spectrum (10 km IFOV from 900 km)
- Spectral coverage: 10 to 100 μm (1000 to 100 cm⁻¹)
 - Requires bilayer beamsplitter with > 92% efficiency 10-100 μm
- Spectral Resolution: 0.625 cm⁻¹ (unapodized), 0.8 cm OPD
- Scan time: 1.4 s
- **NEΔT**: 0.2 K (10 to 60 μm); 0.5 K (60 to 100 μm)
- Optical throughput:
 - Sufficient to meet the NETD requirement for 100 fields in 1.4 s (10 x 10 array)
- Technology to be demonstrated in space-like environment

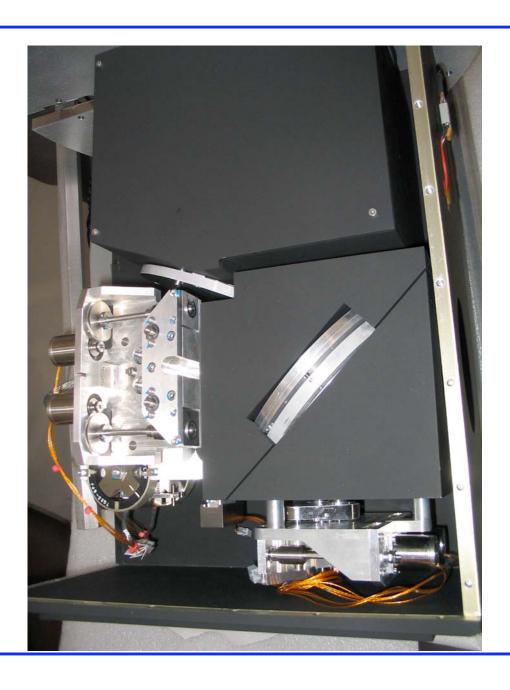


FIRST Key Technology Requirements

- Instrument Type: Fourier Transform Spectrometer
 - Gives greatest possible span of wavelengths in a single instrument
- Beamsplitter: Germanium on polypropylene
 - Excellent response in far-IR, minimal absorption features
- Detectors with kilohertz sampling frequencies
 - To record > 1000 samples in ~ 1 second from orbit
- Single focal plane
 - To simplify the optical design and calibration
- Complete system to be deployed on a high altitude balloon
 - To simulate the space environment



FIRST Interferometer Cube

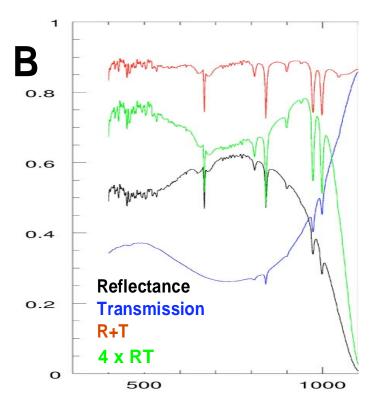




FIRST Broad Bandpass Beamsplitter

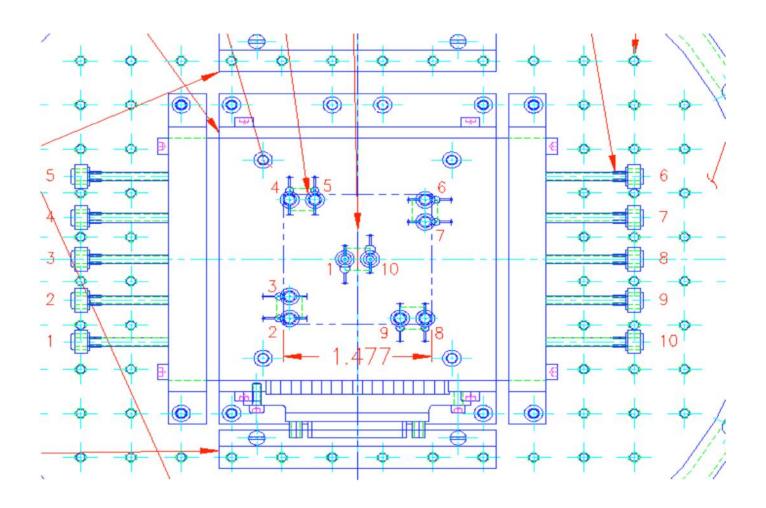


FIRST beamsplitter in mounting ring at USU/SDL



Example FIRST beamsplitter performance curves

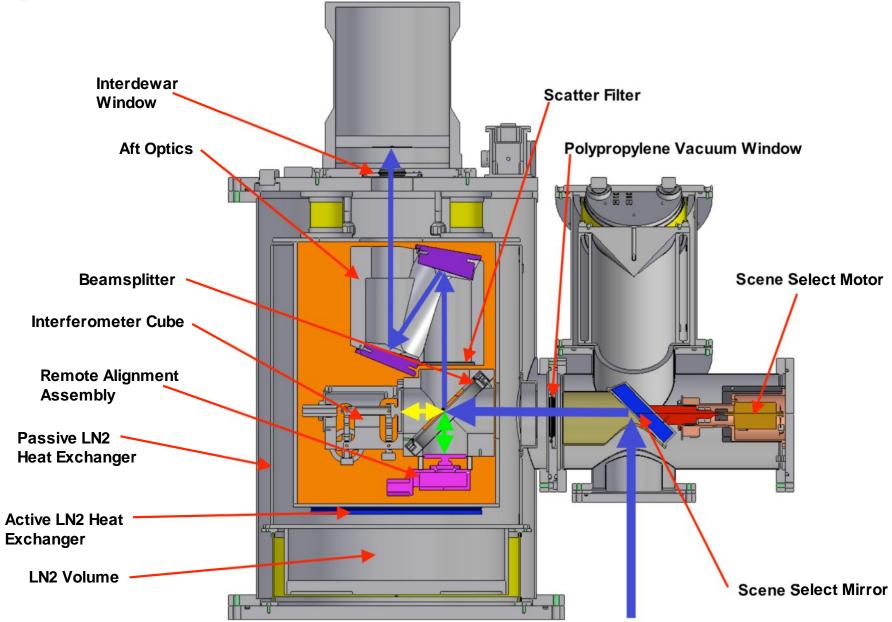
FIRST Focal Plane Layout



Performance of Center (1, 10) and corner (4, 5) detectors will be used to demonstrate that FIRST has sufficient throughput to meet the NETD requirement for a 10 x 10 array

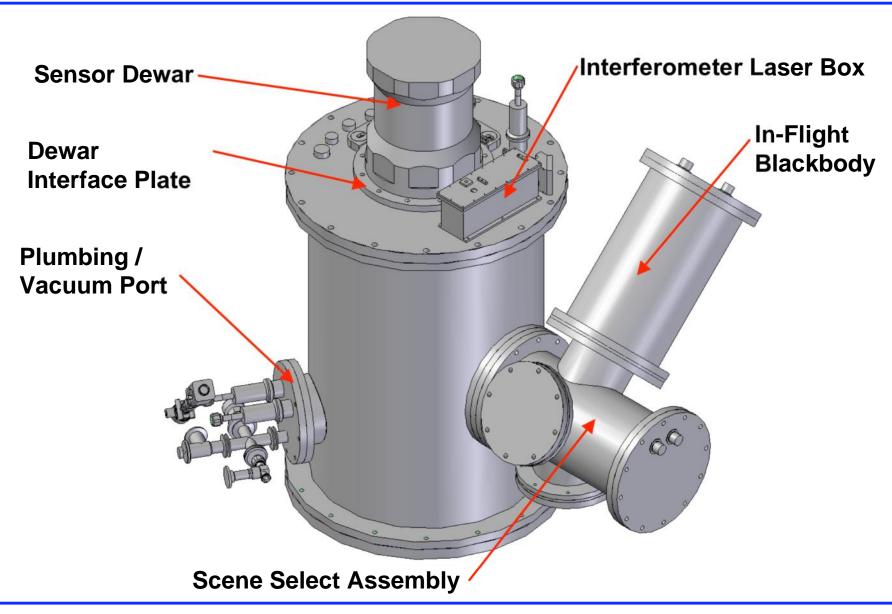


FIRST Balloon Payload System





FIRST Balloon Payload System



FIRST on the Flight Line June 7 2005

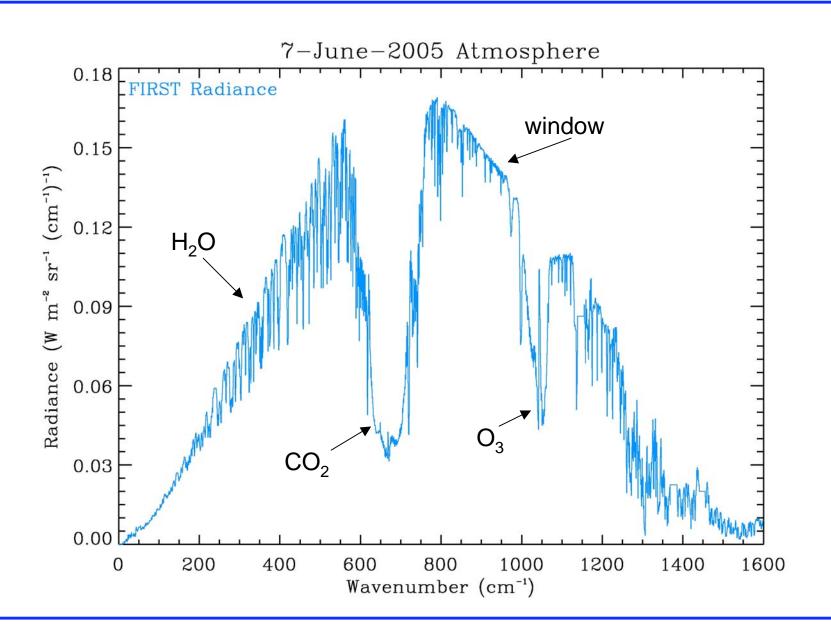


FIRST Flight Specifics

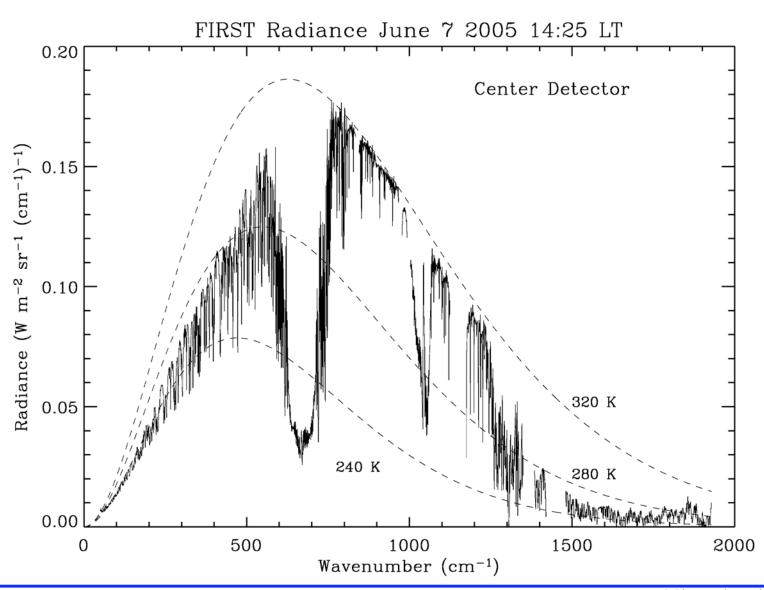
- Launched on 11 M cu ft balloon June 7 2005
- Float altitude of 27 km
- Recorded 5.5 hours of data
- 1.2 km footprint of entire FPA; 0.2 km footprint per detector
- 15,000 interferograms (total) recorded on 10 detectors
- Overflight of AQUA at 2:25 pm local time AIRS, CERES, MODIS
- Essentially coincident footprints FIRST, AQUA instruments
- FIRST met or exceeded technology development goals
- FIRST, AIRS, CERES comparisons in window imply excellent calibration (better than 1 K agreement in skin temperature)

FIRST records complete thermal emission spectrum of the Earth at high spatial and spectral resolution

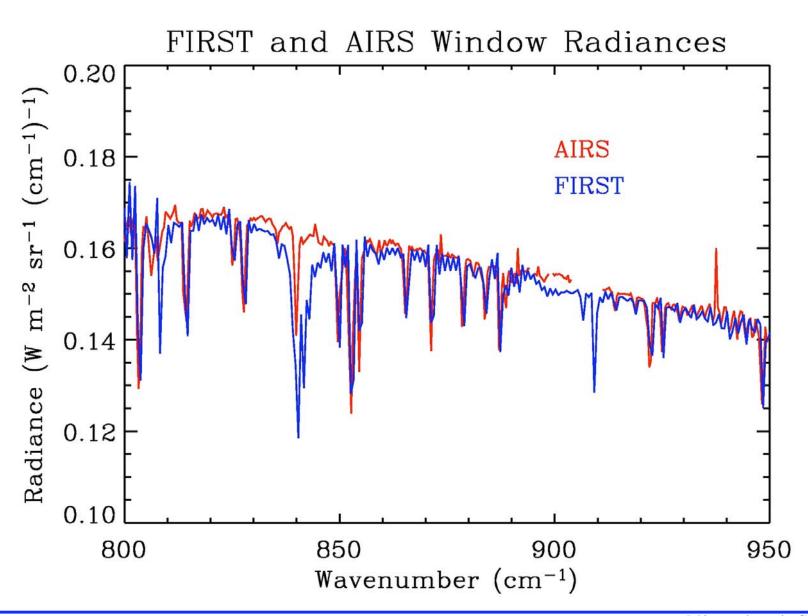
FIRST "First Light" Spectrum



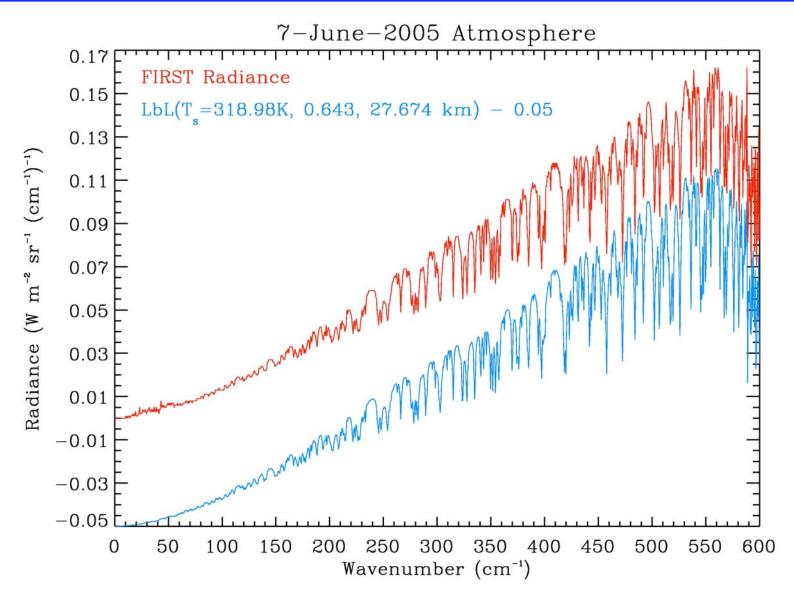
FIRST Spectrum, Center Detector



Comparison of AIRS, FIRST in Window Region

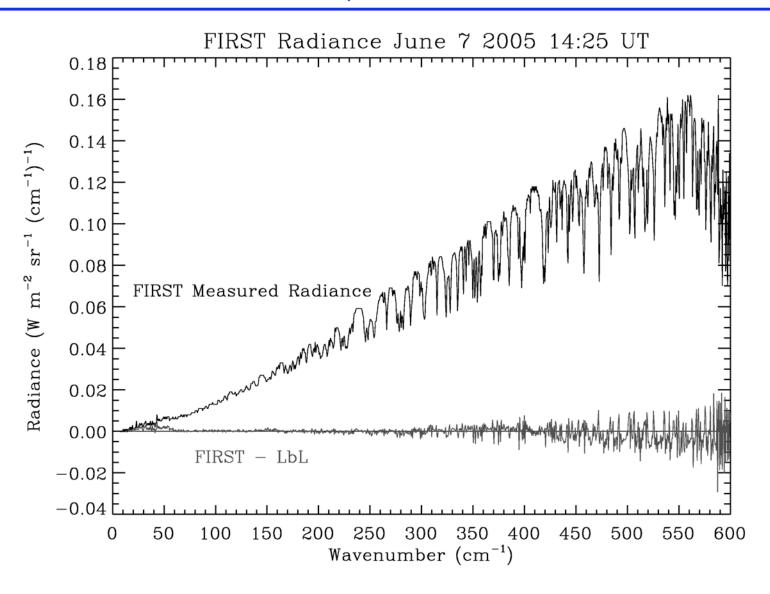


FIRST Spectra Compared with L-b-L Simulation Demonstration of FIRST Recovery of Spectral Structure



Note: FIRST, LbL spectra offset by 0.05 radiance units

FIRST Measured, Calculated Radiance



FIRST → FIDTAP

- FIRST demonstrated FTS, beamsplitter technologies
- FIRST detectors were LHe cooled, COTS bolometers
- LHe cooled system not viable for Earth sensing mission
 - Mass of LHe required likely prohibitive
- NASA and other Gov't Agencies developing mechanical cryocoolers operating at ~ 10 K
- FIDTAP Goal:

Develop far-IR detectors with required sensitivity and speed to operate at temperatures achievable by advanced cryocoolers

Fast, low-temp detectors are remaining technology to be developed to realize FIRST-like measurements from space

FIDTAP – The Partnership

- FIDTAP is a partnership between:
 - NASA ESTO
 - NASA Langley Research Center
 - DRS Technologies, Cypress, CA
- Approach is to extend existing Blocked Impurity Band (BIB) detector technology from ~ 35 μm to > 70 μm

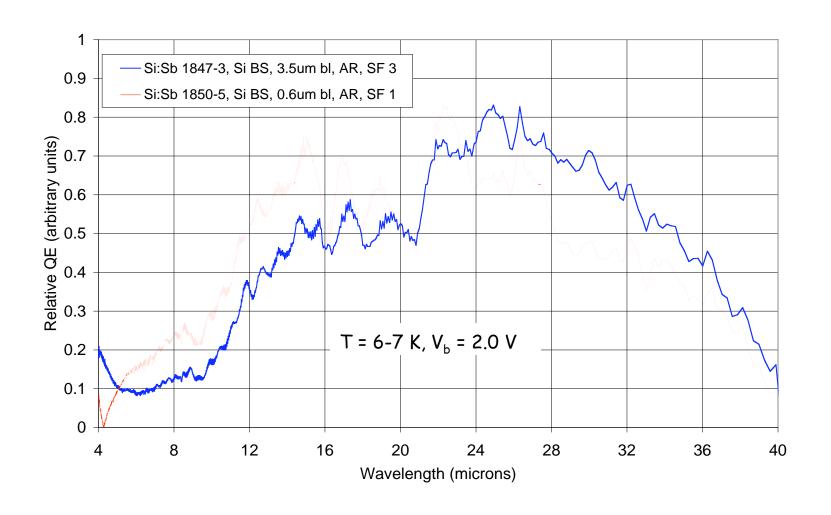
General Concepts

- Silicon BIB detectors are doped with a Group 3 or Group 5 impurity (boron, phosphorus, arsenic, antimony, etc) at a concentrations in the 10¹⁷ range.
- Cut-off wavelength is in the range of 30 to 40 microns for these dopants and increases with dopant concentration
- There is data (*Perera et al.* 1995) that increasing doping into the 10¹⁸ range, will allow cut-off extension to at least 70 microns. Our project explores this as our primary approach to Far-IR BIB detectors.
- Germanium BIB detectors have been demonstrated and they have sensitivity in the Far-IR at dopant concentration in the 10¹⁶ range.
- Neither high quality Ge BIB material nor processing methods are readily available; however, DRS has obtained a few Ge:B layers to process and evaluate as a secondary approach under this project.

FIDTAP BIB Detector Approaches

- 1. Silicon Based (project main approach)
 - Advantage: Existing high-TRL devices responding to 40 microns
 - Challenges: Extending wavelength range into Far-IR;
 managing resulting dark current increase
- 2. Germanium Based (project secondary approach)
 - Advantage: Responds in desired wavelength range; BIB detector has been demonstrated, but low-TRL
 - Challenges: Device processing; improved material for processing

Example of Silicon-Based BIB Starting Point Si:Sb detectors developed for SOPHIA/FORCAST Instrument

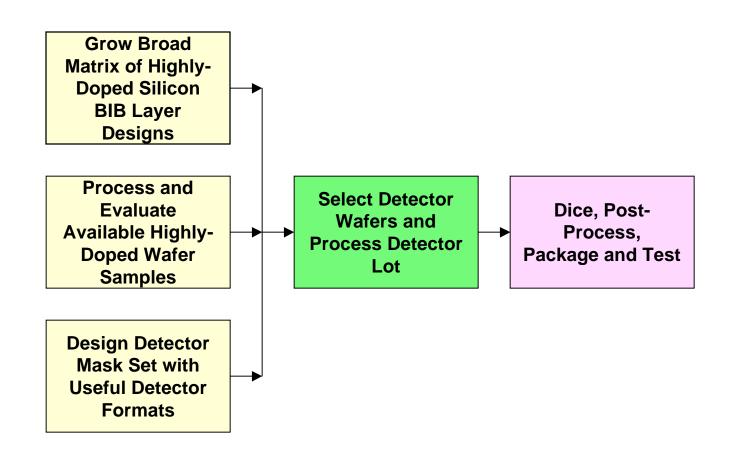


Approach to 10 K Operation

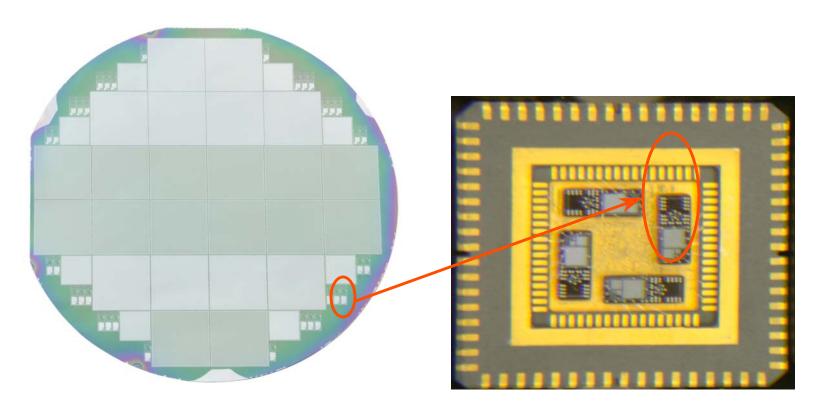
- Simply increasing BIB detector doping to close impurity bandgap for sensitivity to Far-IR
 - Dramatically increases thermal dark current generation rate
 - Forces operation at lower temperature to mitigate dark current growth
- Strategies to overcome this problem involve dopant density control at macroscopic and microscopic levels:
 - Macroscopic: Vary dopant density with depth in detector, keeping density lower where electric field is higher. Reduces electric-fieldassisted thermal generation.
 - Microscopic: Apply modified material growth and processing approaches expected to de-randomize donor locations in lattice-break up statistical clusters. Donor clusters are form mid-impuritygap states through which thermal generation proceeds.
- Through these means 10 K BIB operation may be achieved at useful dark current levels

Far-IR Silicon BIB Detector Development

Block diagram of Silicon BIB detector design, process, and test



Device Examples



Front-side processed 125-mm wafer with detector and arrays of various active areas

Typical appearance of large-area test detectors after post-processing and packaging

FIDTAP - Summary

- Success of FIRST project in demonstrating interferometer and beamsplitter technologies
- Detector technology remaining to be developed for realizing FIRST-like spectra from space
- LHe cooling likely prohibitive for Earth sensing
- Substantial investment in 10 K cryocoolers
- FIDTAP extend existing far-IR technology with cut-off wavelength from 35 μm to > 70 μm
- FIDTAP is a partnership between ESTO, LaRC, DRS
- Contract between LaRC and DRS signed 6/2006 and work is beginning